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Granulometric, Heavy mineral and Field studies of the Lokoja Bassanga and Fugar Sandstone outcrop sequences on the Benin Flank of the Anambra Basin, Southeastern Nigeria

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ABSTRACT

Field study of Basaanga and Fugar Sandstone was embarked upon in order to determine lithostratigraphy profile, their relationship and laboratory studies including granulometric, heavy mineral, and petrographic analysis. The research studies were aimed towards understudying stratigraphic stacking pattern, textural parameters such as grain size, sorting, transportation history, paleoenvironment of deposition and provenance. The Bassanga Sandstone revealed angular grained basal conglomerate deposited on basement rock by flash flood (fluvial) processes deposited close to the source; overlain by fining-upward sequence in cyclic manner with azimuth of ~250^0 paleocurrent direction. Laboratory data deductions show that the average grain size (-0.05 to 2.67 Φ) vary from fine to coarse; sorting (0.18 to 0.86) varies from moderately sorted through moderately well sorted to very well sorted; skewness (0.16 to 4.15) varies from fine to strongly fine skewed. ZTR index (10.0 to 43.2%) from heavy mineral study suggests submature to matured sediment while thin section analysis shows texturally and compositionally mature to sub-mature sublitharenite tending strongly to quartzarenitic rock. The Bassanga sediments were transported by southwest paleocurrent and deposited in fluvial setting. However, Fugar Sandstone is fine grained (2.14-2.98Φ), herringbone structured, fairly bioturbated unit deposited in marginal marine environment; very well sorted (0.18 to 0.28), and strongly fine skewed (2.78-4.5). ZTR index varies from 35.9-50.0% suggestive of mineralogically immature sediments sourced from metamorphic rock (NW) and deposited by paleocurrent in southeasterly direction.

Introduction

Geological studies of Anambra Basin continue to attract attention of many geologists because of the proven hydrocarbon presence. The area of study lies within Latitude 6^{0}55'-6^{0}59'N and Longitude 005^{0}44'-005^{0}53'E on Ifon topographic sheet 284NE (Figure 1). The Anambra Basin ranks almost next to Niger delta in term of richness in hydrocarbon reserves. However, despite enormous amount of work done on the geology of the basin in area of petroleum geology and biostratigraphy, little is carried out on the sedimentology except fantastic works of Nwajide, (1979, 1980, and 1990); Nwajide and Reijers, 1996, 1997) and Ladipo, (1985) to mention a few. Therefore, there is need to further understand the stratigraphic stacking pattern especially the sandstone facies that serves as hydrocarbon reservoirs in terms of textural parameters such as grain size, sorting, transportation history, paleoenvironmet of deposition and provenance. These parameters shall be the cardinal focus of this research work for the sandstone facies.

The Benin Flank has been described as gently plunging northwestern complementing syncline of the Anambra Basin terminating along the NE-SW trending flexure or fault zone (Merki, 1972; Murat, 1972; Whiteman, 1982).

Previous work

A number of researchers have recently carried out relatively appreciable amount of work on the Anambra Basin. Some of the sedimentological works include Tijani et al, (2008) on the Ajali Sandstone characterized by medium-fine sand fractions, whitish, and cross-stratified.

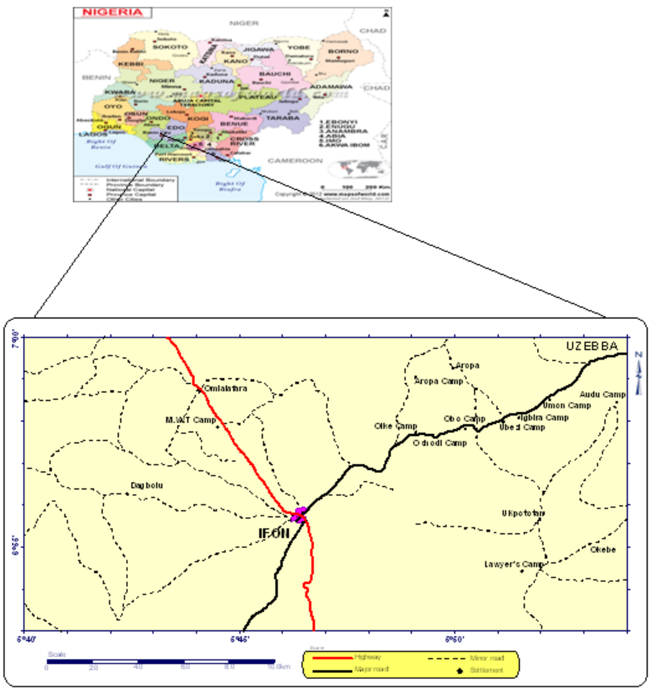

Figure 1: Location and Accessibility Map of the Study Area (Ifon-Uzebba Axis of Benin Flank)

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Ejeh, (2012) established varied environmental conditions varying from fluvial through beach to shallow marine settings based on palynology and sedimentological inferences. Other previous works include Adekoya et al, (2011) on the sedimentological characterization of Ajali Sandstone in Benin Flank of Anambra Basin. Two lithological facies units were differentiated into the lower bioturbated shale and the overlying sandstone unit. The upper sandstone unit was described to be tabular cross-bedded in NNE-SSW paleocurrent direction, fine-coarse grains, poorly sorted sediment classified as Quartz arenite; expressed to be texturally immature facies.

Geologic Setting

Anambra Basin is a major inland sedimentary basin in Nigeria (Fig. 2). Its evolution was based on the theory of the separation of the African and South American plates during the Middle Mesozoic period (Burke, 1972; Nwachukwu, 1972). The theory of Anambra Basin ascertains that it contains Albian-Santonian sediments in the eastern half referred to as Abakaliki depression while the other half proto-Anambra was platform consisting of post Santonian sediments (Nwajide and Reijer, 1997; Murat, 1972; Nwachukwu, 1972; Weber and Doukoru, 1975; Benkhelil, 1982;; Nwajide and Reijers, 1996; Mode and Onuoha, 2006; Obi, 2000).

Recent research work has shown that even though the western part of Anambra Basin consists mainly of post Santonian sediments but they are restricted probably mainly to the southern part of Onisha. The northern part of Onisha and west of it in Edo state have proved otherwise that the basin contains Middle Cretaceous to Late Tertiary sediments (Ola-Buraimo and Akaegbobi, 2012; Ola-Buraimo, 2013a; Ola-Buraimo, 2013b; Ola-Buraimo and Akaegbobi, 2013b). The Santonian period marked the stage when the basin experienced tectonic event that involved deformation, folding, faulting and upliftment of the pre-Santonian sediments in the Onisha area which evolved as depression to the uplift (Benkhelil, 1987). However, this depression was limited in extent excluding the northern part of the Anambra Basin and southwestern part of the basin (Ola-Buraimo and Akaegbobi, 2013b). The oldest sediment in the Anambra Basin has been erroneously placed to be Nkporo Group (Nwajide, 1970) but recent study shows that apart from Southern Onisha area, Asu-River Group dated Albian to Lower Cenomanian is the oldest sediment in Anambra Basin (Ola-Buraimo and Akaegbobi, 2013b).

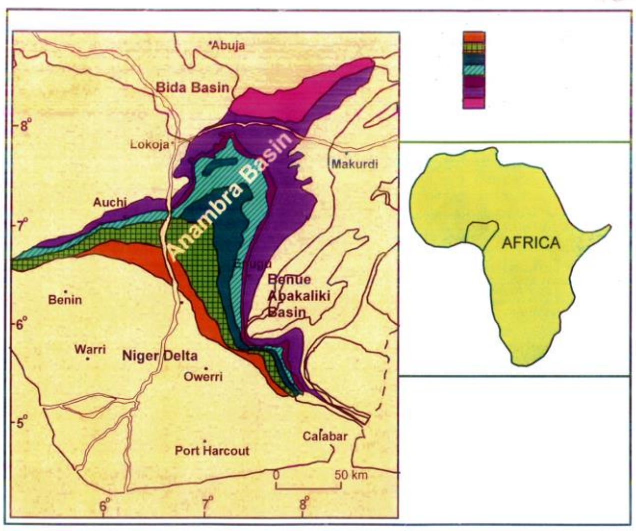


Figure 2: Geological Sketch Map of Anambra Basin Showing the Extension of Benin Flank within the Study Area. (Modified from Geological Map of Nigeria, GSN1994)

The stratigraphic sequence of Anambra Basin have been discussed extensively by several workers including Reymen, (1965); Dessauvagie, (1974); Murat, (1972); Ladipo, (1988); Agagu et al, (1985); Ola-Buraimo and Akaegbobi, (2013b). Thus, unlike the assumption that sedimentation in Anambra Basin started and ranged from Late Santonian to Eocene; it has been succinctly expressed in the research work of Ola-Buraimo and Akaegbobi, (2012) that the Ogwashi-Asaba Formation which forms part of the lithostratigraphy of the basin was dated Late Miocene to Pliocene age based on the dinoflagellate cysts presence. It has also been advanced that the oldest sediment in the basin like the other known parts is Asu-River Group dated Albian to Lower Cenomanian (Ola-Buraimo and Akaegbobi, 2013b) through the use of pollen and spores assemblages.

The Asu-River Group has varied lithologic units, dark grey to black colored shale, variously ferruginized, deposited in environment varying from continental through marginal marine to open marine systems (Ola-Buraimo and Akaegbobi, 2013b). This is overlain by Eze-Aku Formation, composed of predominantly dark shale, dated Upper Cenomanian to Turonian (Ola-Buraimo, 2013a). The overlying sequence is Awgu Shale dated Coniacian (Ola-Buraimo, 2013b) marked the end of the first phase of sedimentation in Anambra Basin before the commencement of tectonic event in the Santonian. The dislocation of the depocenter into the Anambra platform resulted into the deposition of the Nkporo Shale (Nwajide, 1990). The Nkporo Group comprises of Nkporo Shale, Owelli Sandstone, and Enugu Shale dated Late Campanian (Reyment, 1965; Obi, 2001). However, study based on palynoogy has dated the Asata/Nkporo Shale to be Campanian-Lowest Maastrichtian age (Ola-Buraimo and Akaegbobi, 2013b).

The Nkporo Shale is overlain by Mamu Formation deposited in Early Maastrichtian (Kogbe, 1989; Obi, 2000). It is composed of siltstone, shale, coal seams and sandstone (Kogbe, 1989). The Mamu Formation was dated recently to range from Lower to Middle Maastrichtian based on pollen and spores recovered (Ogala et al, 2009). Ajali sandstone dated Maastrichtian age overlies the Mamu Formation (Reyment, 1965; Nwajide, 1990). The sandstone is unconsolidated, coarse to fine grained, poorly cemented, mudstone and siltstone in nature (Kogbe, 1989).

The Ajali Sandstone is overlain by diachronous Nsukka Formation (Maastrichtian- Danian) which is also known as Upper Coal Measures (Reyment, 1965; Obi, 2001); but it has been specifically assigned Late Maastrichtian based on palynomorphs recovery (Bankole and Ola-Buraimo, 2013 in press). Imo Shale (Paleocene) overlies the Nsukka Formation (Nwajide, 1990) while it is successively overlain by Ameki Group, dated Eocene (Obi, 2000). This is followed by Ogwasi-Asaba Formation, composed of dark grey shale and sandy shale; characterized by evidence of sediment reworking; dated Late Miocene-Pliocene (Ola-Buraimo and Akaegbobi, 2012). The most recent sediment is the Benin Formation deposited by fluvial processes is suggested to belong to Pliocene to Recent in age based on stratigraphic position. The detail stratigraphy of the basin is given below in Table 1.

Methodology

The methods of research study involved both field and laboratory studies. The field study involved field mapping exercise covering the area under study. The study includes detail information on the lithostratigraphy profile of outcrop exposures by noting the textural features such as grain size, angularity, sorting, structures such as bedding, lamination; fossil content, bioturbation and type of ichnofossils present. Other important data include dip, and structural orientation like fracture trends. Field materials taken along include base map, field notebook, sample bags, Global Positioning System (GPS), Compass clinometers, hammer, chisel, measuring tape, masking tape, markers, and digital camera.

Table 1: Correlation Chart for Early Cretaceous strata in southeastern Nigeria (After Nwajide, 1990)

AGE		ABAKALIKI-ANAMBRA BASIN	AFKPO BASIN
M.Y 30	Oligocene	Ogwashi-Asaba formation	Ogwashi-Asaba formation
54.9	Eocene	Ameki/Nanka formation/ Nsuebe sandstone(Ameki group)	Ameki formation
65	Paleocene	Imo formation Nsukka formation	Imo formation Nsukka formation
73	Maastrichtian	Ajali formation Mamu formation	Ajali formation Mamu formation
83	Campanian	Nkporo Oweli formation/Enugu shale	Npkoro shale/Afikpo sandstone
87.5	Santonian		Non-deposition/erosion
88.5	Coniacian	Agbani sandstone/ Awgu shale	
	Turonian	Eze Aku Group	Eze Aku Group (include Amasiri sandstone)
93 100	Cenomanian-Albian	Asu River Group	Asu River Group
119	Aptian Barremian Hauterivian	Unnamed Group	
PRECAMBRIAN		BASEMENT COMPLEX	

Sampling technique involved spot sampling whereby representative sampling of rock unit from which samples were collected at different intervals in each outcrop. In-situ samples, fresh, unweathered and representative sampling was ensured. However, in the case of Fugar Sandstone, scooping of the friable sandstone was required because of poor cementation of the grains.

A total of 6 samples were collected from the Lokoja Bassange Formation exposed at Ori Ohin village with coordinates N06^{0}57’55.6” E005^{0}44’37.7”, while another set of 5 samples were collected from Fugar Sandstone located on coordinate N06^{0}59’28.1” E005^{0}53’17.4”. The sandstones were crushed and dried, gently disaggregated into particles using hand. The sandstone samples were subjected to different laboratory processes such as granulometric, heavy mineral, thin section and petrographic studies following standard laboratory procedures.

Result and Discussion

Field Observation

Three outcrop sections and a quarry exposure situated at different locations were studied; though the sedimentary structures have been partially to completely obliterated due to prolong weathering and human activities in some cases.

Location LB: Ori Ohin village (06^{0}57’55.6” E005^{0}44’37.7”)

The location LB is a road-cut exposure before the village. It reveals a sequence that is associated with basal gritty conglomeratic sandstone, composed mainly of feldspathic mineral grains. It is overlain by ferruginized sandstone, conglomeratic at the base and cross laminated (Figure 3).

The upper cross-bedded unit is characterized by iron cemented fracture trending 226^0 and 232^0. The lithological sequence further shows very angular pebbles that constitutes the conglomerate (Fig. 3). This angularity in grain shape suggests that fluvial processes were responsible for the weathering, transportation and deposition of the clast particles transported under very high energy current or flash floods but deposited not too far away from the parent rock. The lithologic profile fines upward showing evidence of grading in a cyclic manner (Fig. 4). The planar structure has forset of beds with azimuth of ~250^0 paleocurrent direction.

Figure 3: Conglomeratic feldspathic sandstone (cyclic deposit at Ori Ohin

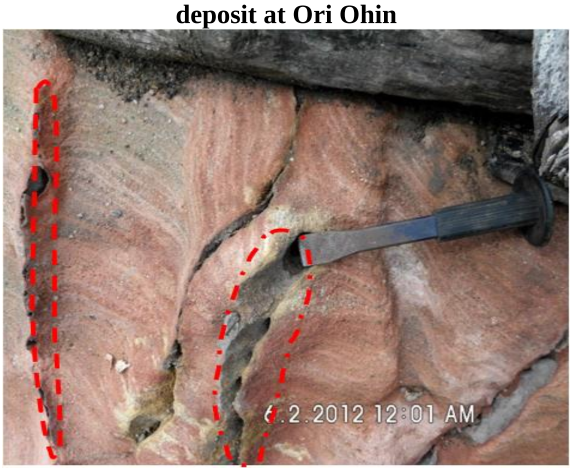


Figure 4: Burrow Mottling on the Lokoja Bassange Sandstone

Other important feature is bioturbation which depicts degree of past activities of organisms that inhabited the facies in terms of their feeding habit, locomotion and burrowing. However, the amount of bioturbation is fair; this might be responsible for the preservation of the bedding structures. Ichnofossil shows deep burrows like that of skolithos which are apparent on the rock surfaces, suggestive of a form of escape habitat like that of brackish environment belonging to a marginal marine setting (Fig. 4) .

Laboratory Data Deductions

Laboratory studies carried out on the sandstone samples were statistically computed to generate the Means, Inclusive Standard Deviation and Skewness in order to deduce the average grain size, sorting and spatial distribution of the grains, transportation history and paleoenvironment of deposition.

Mean

The mean values are used to determine the average grain size of the sediment which could be classified to be very coarse, coarse, medium grained sandstone, fine or silt sized sandstone

(Folk and Ward, 1957). The variation in sizes is in response to current energy whether high, medium or low. This is indirectly in relationship to the course of the river whether it was upper, middle or at lower course. It may as well be related to lateral variation in response to hydraulic sorting and abrasion. Laterally, sand grains tend to decrease from the upper to lower course of the river. Thus, the direction of decrease in size could suggest paleocurrent direction.

$$\text{Mean size} = \frac{\o16 + \o50 + \o84}{3}$$

Generally, only one sample (LB4) has an average grain size of 2.67 for samples classified to have greater than two (>2.0). This suggests that the sample has fine grained size particles, probably tending towards a siltstone facies. The samples LB5 and LB6 have mean values ranging from 0.28-0.73 suggesting coarse grained sandstones. However, other samples with negative mean values are samples LB1-LB3 with average grain size values ranging from -0.05 to -0.18 suggestive of very coarse sand category. (See Table 2).

Therefore, the lower the mean values for the analyzed samples, the greater the average grain size; while the greater the mean value, the smaller the grain size.

Table 2: Graphic Mean data of Lokoja Bassange Sandstones

Sample No	Calculated Mean	Descriptive terms
LBI	-0.05	Very Coarse sand
LB2	-0.12	Very Coarse sand
LB3	-0.18	Very Coarse sand
LB4	2.67	Fine sand
LB5	0.38	Coarse sand
LB6	0.73	Coarse sand

Graphic Standard Deviation (sorting)

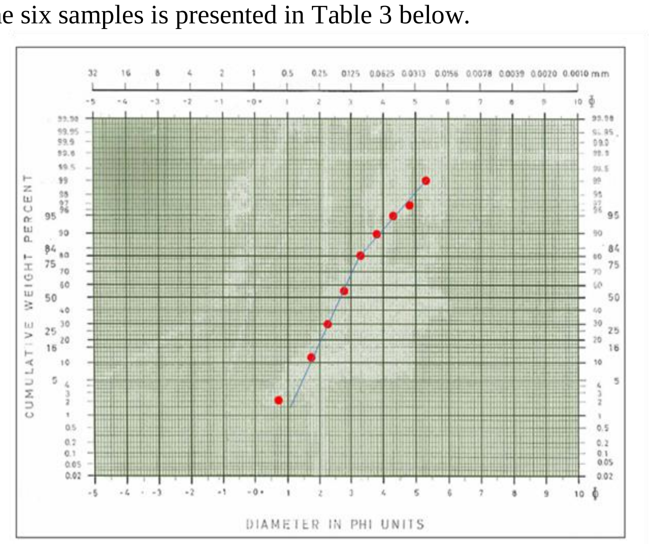
Graphic Standard Deviation is another important parameter calculated and used for the interpretation of the granulometric analysis. It is determined from the Log probability curves for the samples LB1-LB6.

$$\sigma_1 = \frac{\O84 - \O16}{4} + \frac{\O95 - \O5}{6.6}$$

(Folk and Ward, 1957)

The percentiles- Ø95, Ø84, Ø16 and Ø5 were derived from cumulative percentage vs Grain size curves for the analyzed samples (Figures 6-7). The Standard Deviation (σ_1) measures the scatter around the mean. Therefore, it describes the transportation history of the sediment which may be dependent on factors such as source, depositional environment, rate of deposition and provenance.

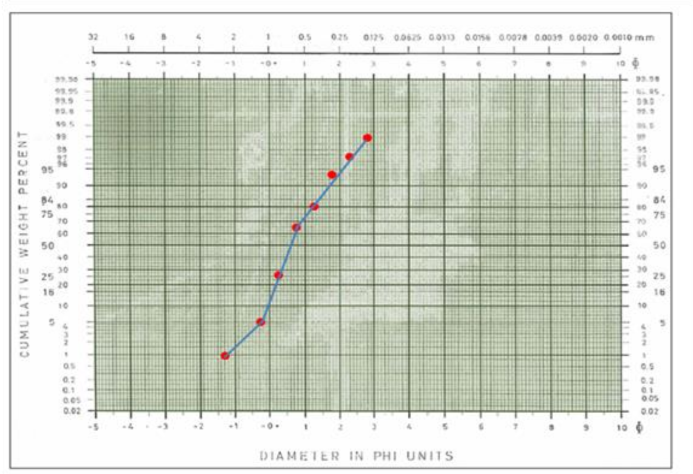
In this research work, the calculated Standard Deviation for the six samples is presented in Table 3 below.



	Fi ne	medi um	coar se	fi ne	Medi um	coar se	Fi ne	Medi um	Coar se
Cl ay	SILT			SAND			GRAVEL		

0.002 0.06 2 60

Figure 6: Log probability curve for Lokoja Bassange Sandstone (Sample LB4)



	Fi ne	medi um	coar se	fi ne	Medi um	coar se	Fi ne	medi um	Coar se
Cl ay	SILT			SAND			GRAVEL		

0.002 0.06 2 60

Figure 7: Log probability curve for Lokoja Bassange Sandstone (Sample LB6)

The graphic representation shown in sample LB6 displays distinctive three segments which represent three main mechanisms of sediment transportation. The lower part (tail) represents the rolling of particles heavier than energy capability to suspend, while the middle segment represents the saltation of particles and the upper (head) of the segment represents the suspended particles of the sediment (Fig. 7). Sample LB4 does not show similar graphic like sample LB6 (Fig. 6). This could imply that the sample did not have well developed tail. This means that there was little or no amount of coarse grained particles in the sediment; thereby, rolling mechanism is absent or not well represented but significantly represented by saltation and suspension of relatively finer grain particles.

Table 3: Graphic Standard Deviation Results data interpretation

Sample No	Calculated values for sorting	Descriptive terms for sorting
LBI	0.27	Very well sorted
LB2	0.18	Very well sorted
LB3	0.69	Moderately well sorted
LB4	0.86	Moderately sorted
LB5	0.70	Moderately well sorted
LB6	0.68	Moderately well sorted

The data set presented in Table 3 shows that three main categories of sorting are present from the analyzed samples due to transportation history. The moderately sorted particles belong to sample Lb4 with calculated graphic standard deviation value of 0.86, while the moderately well sorted sediments are present in samples LB3, LB5 and LB6. The very well sorted sediments are characterized by calculated graphic standard deviation values ranging from 0.18-0.27 belonging to samplesLB1 and LB2.

However, sample LB4 is categorized as moderately sorted because it has sorting value of 0.86 within a limit of 0.71-1.00. This shows that even though the sediment has an average grain size that is fine but the medium of transportation which was river had transported the sediments relatively farer away from the source. This was associated with relatively consistent velocity or energy of transportation; whereby greater parts of the larger grains have been dropped and the water was relatively consistent in transportation. The sediment grains are suggested to be reworked sediments (recycle) within the middle to lower course of the river channel.

Samples LB3, LB5 and LB6 have sorting values ranging from 0.98-0.70, fall within graphic standard deviation of 0.5-0.71; categorized as moderately well sorted. This is better sorted than moderately sorted. Thus, the very coarse to coarse sediments have been subjected to long distance of transportation under a moderate energy of transportation, relatively fair constant energy of transportation over a low gradient topography accompanied with relatively lower rate of sedimentation.

Samples L1 and L2 are defined to be very well sorted in nature despite the fact that the average grain size is very coarse (Table 3). They have sorting values ranging from 0.18-0.27 within a limit of < 0.35. This tend to portray that the sediments were transported over a long distance under a high and steady energy of transportation, whereby, it allowed smaller grains to have been winnowed and carried away from the water system through hydraulic sorting. The sediments are suggested to be recycled grains deposited under relatively lower rate of sedimentation.

Therefore, in term of reservoir property (porosity and permeability) the porosity tend to increase from moderately sorted (LB4) through moderately well sorted (Lb3, Lb5 and LB6) to very well sorted (Lb1 and LB2) sandstones.

Skewness

This is another statistical parameter calculated from the Log probability curves for the 6 samples. The essence of skewness is to serve as a measure of symmetry in the scatter of distribution. It can as well be described as the degree of lopsidedness of the curve. Therefore, Inclusive Graphic Skewness was calculated:

$$SK_1 = \frac{Ø16 + Ø84 - 2Ø50}{2(Ø84 - Ø16)} + \frac{Ø5 + Ø95 - 2Ø50}{2(Ø95 - Ø5)}$$

(Folk and Ward, 1957)

The data obtained from the calculated Inclusive Graphic Skewness is presented in Table 4 below.

Table 4: Showing calculated Inclusive Graphic Skewness for Sample LB1-LB6

Sample No	Calculated values of skewness	Descriptive terms for skewness
LBI	2.91	Strongly fine skewed
LB2	4.15	Strongly fine skewed
LB3	0.69	Strongly fine skewed
LB4	0.16	Fine skewed
LB5	1.34	Strongly fine skewed
LB6	0.27	Fine skewed

All the samples analyzed for the Bassange sandstones are positively skewed, suggesting that they contain more of fine particles in the sediment assemblage than coarse particles. Such phenomenon may be a resultant of deposition in a very low gradient topography, transported under relatively consistently low energy current probably under a meandering regime (LB4 and LB6) and further down in a flood plain system as suggested for strongly skewed samples such as LB1, LB2, LB3 and LB5.

Paleoenvironmet of Deposition

Evidence from multivariate parameter shown in Table 5 suggest a fluviatile depositional environment which is in contrary to two samples suggested to belong to beach environment as evident from the bivariate plots shown in Figures 8 and 9. The continental environment is suggested for LB1, LB2, LB3 and LB6; while beach environment is suggested for the samples LB4 and LB5.

Histogram plots represented in Figure 10 for Lokoja Bassange Formation show a representative of a trimodal character for the basal units (samples LB1 and LB2) and a weak bimodal for (LB3) and a weak unimodal for the upper units (samples LB4, LB5 and LB6).

Table 5: Calculated Multivariate based on Sahu (1964) using Shallow Marine versus Fluvial Determinants.

Sample No	Calculated result	Interpreted environment
LB1	-22.98	Fluvial
LB2	-29.09	Fluvial
LB3	-12.17	Fluvial
LB4	-8.74	Fluvial
LB5	-15.16	Fluvial
LB6	-9.79	Fluvial

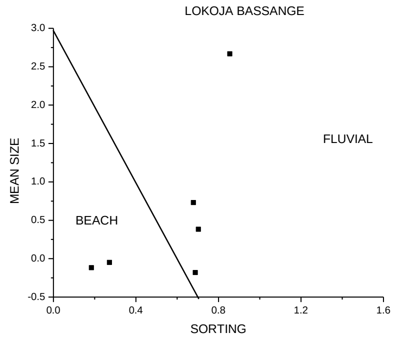


Figure 8: Bivariate Plot of mean size against Sorting for Lokoja Bassange (After Friedman, 1967)

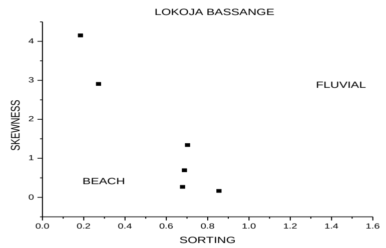


Figure 9: Bivariate Plot of mean size against Sorting for Lokoja Bassange Sandstone (After Friedman, 1967)

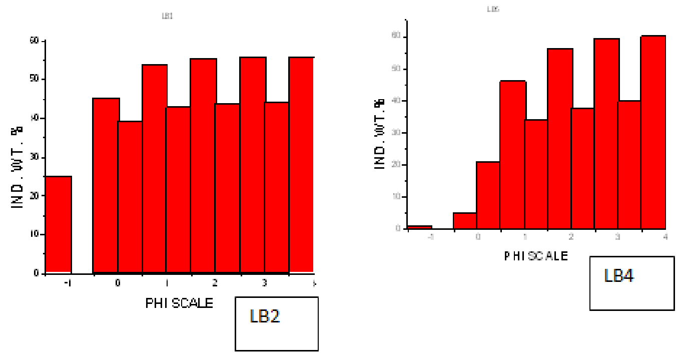


Figure 10: Histogram plot of samples LB2 and LB4

Paleocurrent Data

Paleocurrent data was obtained from dip values obtained from the field of Bassanga Sandstone located at Orin Ohin village. The dip values of cross-beddings obtained are as follows: 250/12°W, 238/18°W, 232/22°W, 238/20°W, 252/14°W, 244/16°W, 234/24°W, 236/30°W, 254/10°W, 250/14°W, 252/8° W, 248/12°W, 246/18°W. Classification of the measured dip in terms of frequency and frequency percentage is presented in Table 6.

Table 6: Paleocurrent direction of the cross-bedded azimuths of Lokoja Bassange Sandstone

CLASS INTERVAL	TALLY	FREQUENCY	FREQUENCY (%)
200 - 230	1111 1111 111	13	100
231 - 260	-		
261 - 290	-		

The paleocurrent analysis (paleocurrent indicator analysis) involves measurement of the orientation of key sedimentary structures formed during transport of sediment by moving fluid. It provides direct information about the orientation of the sedimentary systems. The study as well yields information on the flow direction of the rives, longshore currents, sediment gravity flows, and paleowinds.

The Table 7 below shows the data obtained from the calculated variants for the azimuth. The paleocurrent direction from the rose diagram indicates a southwest trend while its provenance direction is suggested to be mainly from the basement complex of the northwest direction even though there could be some amount of grain supply from the western basement rocks (Figure 11).

Mean vector Azimuth = Tan^{-1} Σ {(sin A)/ (Cos A}

Where Σ Sin A= –11.6043

Σ COSA = -5.61984

Therefore, MVA = $Tan-^{1}$ –11.6043 / –5.61984

Tan^{-1} 2.064 = 64

Hence MVA = 64 + 180

= 244°

Variance = Σ $(A – MVA)^2$ /(N – 1)

A = azimuth

MVA = Computed mean vector azimuth (244°)

N = total number of outcome (13)

Therefore, Variance = 700/ (13 – 1)

= 700/12

= 58.

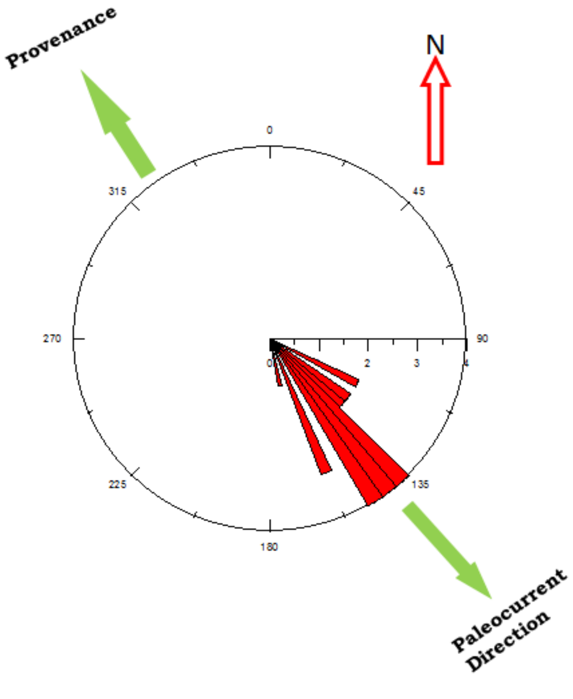


Figure 11: Rose Diagram showing Paleocurrent Pattern for Lokoja Bassange Sandstone

Heavy mineral petrographical studies of samples from Lokoja Bassange Sandstone indicate presence of zircon, tourmaline and rutile. Other minerals present are garnet, epidote, chloritoid, titanite, and spinel together with the opaque minerals suggestive of acid igneous and metamorphic source rocks. The ZTR index calculated range from 10.0% to 43.20% suggestive of matured sediments (Hubert, 1962). ZTR plot reveals that rutile is the most abundant of the ultrastable minerals pointing to a metamorphic source rock. Further evidence from the major compositional framework obtained from thin section petrographic studies shown in Figures 12 and 13 suggest texturally and compositionally mature to sub-mature sublitharenite tending strongly to quartzarenitic rock classification (Fig.13). The position of the guartz grains on the ternary diagram shows that they are tending toward quartz arenite; a mineral composition that suggest almost complete removal of matrix which could constitute the rock fragment and digested feldspar into clay that are negligible (Table 8). Therefore, the coarse grain sediments and other fine grain samples are suggested to be recycled particles as evident from the ternary diagram of framework composition of samples LB1-LB6 of the Bassange Sandstones (Fig. 14).

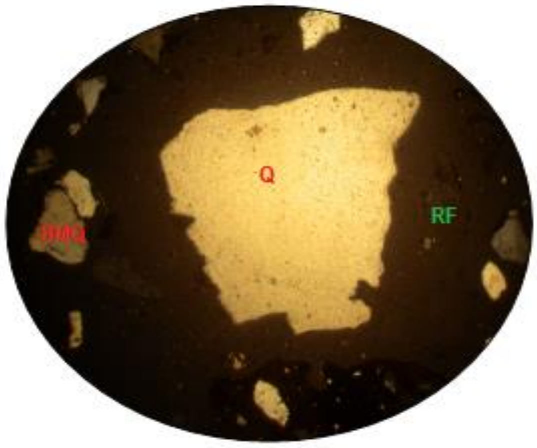


Figure 12: (Cross polarized light): Photomicrograph of Lokoja Bassange Sandstones

Q= Quartz (isolated grain) indicating textural maturity that has been transported too far away from the source and probably recycled.

SMQ= Stretched Metamorphic Quartz: formed when quartz-bearing rock is sheared or strained in the absence of recrystallization.

RF= Rock Fragment.

The grains are mostly quartz with a few (weathered, dark) silt-size feldspars (Table 8), moderately to well sorted and sub-angular (textural maturity) polycrystalline quartz. The Quartz has low relief (in plane polarized light).

Feldspars have a mucky appearance due to alteration to clays. The primary Petrographic characteristics show that in these sandstones are both compositional and texturally mature.

Fugar Sandstone

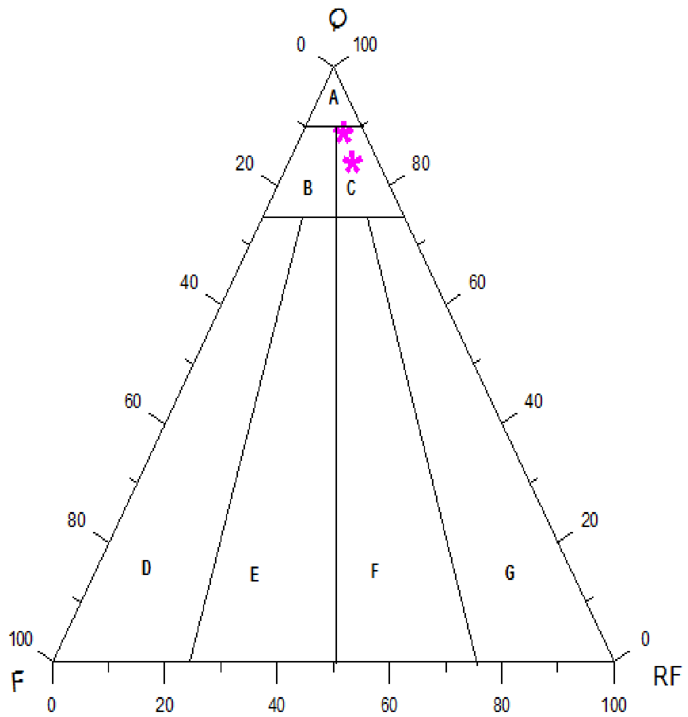
The Fugar Sandstone outcrop is well exposed along Ifon-Uzebba Road with a coordinate of N 06° 59′ 28.1″ E 005° 53′ 17.4″. The Fugar Sandstne outcrop has an estimated elevation of about 226m. The exposure was in a local quarry; here the formation consists mainly of friable, moderately well sorted, whitish, fine to medium grained sandstone with overall thickness of about 45ft (13.6m) in a coarsening upward sequence as indicated (Fig. 15).

Table 7: Paleocurrent analysis data of Lokoja Baassange Sandstone in the study area

S/N	Azimuth (A)	Dip (D)	Sin (A)	Cos (A)	Cos (D)	b = COS (A * D)	a = Sin (A)*cos (D)	$(AZ\text{-}MVA)^2$
1	250	12	-0.9397	-0.342	0.978	-0.3345	-0.9190	36
2	238	18	-0.8480	-0.5299	0.951	-0.5039	-0.8064	36
3	232	22	-0.7880	-0.6157	0.9272	-0.5709	-0.731	144
4	238	20	-0.8480	-0.5299	0.9397	-0.4979	-0.7969	36
5	252	14	-0.9511	-0.3090	0.9703	-0.2998	-0.9229	64
6	244	16	-0.8988	-0.4384	0.9613	-0.4214	-0.8640	0
7	234	24	-0.8090	-0.5878	0.9135	-0.5369	-0.7390	100
8	236	30	-0.829	-0.5592	0.8660	-0.4843	-0.7179	64
9	254	10	-0.9613	-0.2756	0.9848	-0.2714	-0.9467	100
10	250	14	-0.9397	-0.3420	0.9703	-0.3318	-0.9118	36
11	252	8	-0.951	-0.3090	0.9903	-0.306	-0.9418	64
12	248	12	-0.9272	-0.3746	0.978	-0.3664	-0.9068	16
13	246	18	-0.9135	-0.4067	0.9511	-0.387	-0.8688	4
			Σ11.6043	Σ 5.61984				Σ 700

Table 8: Percentage Abundance for Quartz, Feldspar and Rock Fragment.

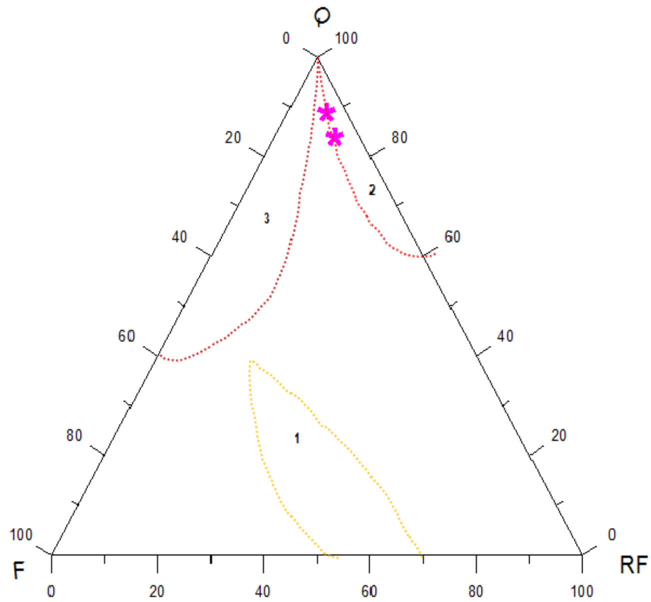
LOCATION	Quartz (Q)%	Feldspar (F) %	Rock Fragment (RF) %
LB1	89.09	3.64	7.27
LB2	84.09	4.55	11.36



A= QUARTZ ARENITE B=SUBARKOSE
C=SUBLITHARENITE D=ARKOSE
E= LITHIC ARKOSE F= FELDSPATHIC LITHARENITE G= LITHARENITE

Figure 13: Ternary Diagram of Framework composition of Lokoja Bassange Sandstones Showing Rock typ es (After Folk, 1968).

Revinement surfaces are apparent features of the Fugar Sandstone (Fig. 16). Revinemet surface is an erosional surface suggestive of short incursion or influence of fluviatile erosional process. It is further characterized by typical structures such as cross beds from which it derived the names false-bedded sandstone, Herringbone cross-beds, associated with bedded and laminated sandstone units, fairly-well rich in iron mineral. (Figs. 17, 18).



1= Magmatic Arc provenance
2= Recycled Orogen Provenance
3= Continental Block Provenance

Figure 14: Paleotectonic Setting of Lokoja Bassange Sandstones (After Dickinson and Suczek, 1979)

Figure 15: Vertical Section of Bioturbated Sandstone Lithofacies Showing Trace Fossils of Ophiomorpha.

Figure 16: Showing a Revinement surface (an erosional surface within a set of cross beds) truncating some of the cross-beds.

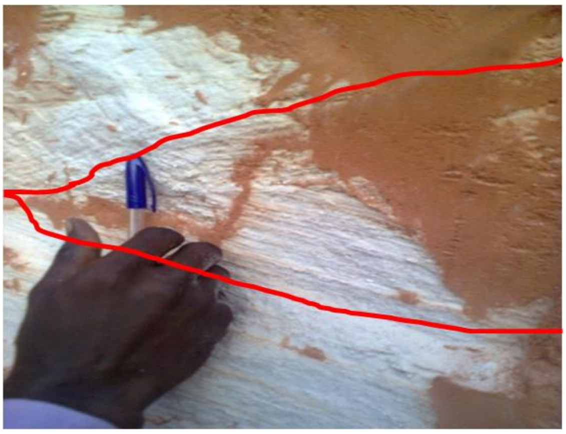


Figure 17: Herringbone structure (bi-directional stratification) indicative of Tidal environment

Figure 18: Southwest paleocurrent direction of the cross beds in the Fugar Formation along Ifon Uzebba Road.

Paleocurrent direction illustrated in Figure 18 was determined from field measurements on cross bed foresets (azimuth ~140°, dip ~70°W) shown in Figure 25. Bioturbation expression (Fig. 15) is fair indicating ichnofossil of Ophiomorpha burrows criss-crossing the various beds suggestive of marine shoreface environment.

The herringbone cross-stratification shown in Figure 17 could have resulted from a tidal current flowing predominantly in one direction for a period of time, followed by a change in the pattern of tidal flow that results in another period of opposite flow. Under favorable circumstances, such bipolar cross-stratification may have been formed in a single vertical section produced by alternating directions of migration of ripples or dunes. The herringbone pattern is characteristic of tidal sedimentation (Dalrymple & Choi 2007). The abundance of Ophiomorpha burrows shown in Figure 16 suggests sediments were deposited in tidal environment or littoral system.

Laboratory Data Deductions

The results and subsequent interpretations presented under granulometric study are from grain size distribution analysis. Evidence from univariate parameters show that Fugar Sandstone is fine in size- 2.14 to 2.98Φ (Table 9), very well sorted- 0.18 to 0.28 (Table 10); strongly fine skewed- 2.78 to 4.45 (Table 11).

Table 9: Graphic mean data interpretation for the study locations

Sample No	Calculated Mean	Descriptive terms
A1	2.98	Fine sand
A2	2.88	Fine sand
A3	2.69	Fine sand
A4	2.27	Fine sand
A5	2.14	Fine sand

Table 10: Graphic Standard Deviation Results data interpretation

Sample No	Calculated result (Sorting)	Descriptive terms
A1	0.28	Very well sorted
A2	0.24	Very well sorted
A3	0.22	Very well sorted
A4	0.18	Very well sorted
A5	0.18	Very well sorted

The sediments are generally very well sorted; grain size is fine. This suggests that that the sediments were under the influence of bidirectional energy current that allowed a lot of winnowing to take place whereby clay size particles were winnowed away from the sediment assemblage by the marine current leaving behind fine sized grains of a river-mouth facies to beach sediment deposits.

Table 11: Skewness data interpretation for sandstones in the study area

Sample No	Calculated result	Descriptive terms
A1	4.45	Strongly fine skewed
A2	4.27	Strongly fine skewed
A3	3.44	Strongly fine skewed
A4	2.92	Strongly fine skewed
A5	2.78	Strongly fine skewed

It is deduced from the Log probability curves that the sediments were transported under three to two transportation mechanisms which involved rolling, saltation and suspension (Fig.19) or only saltation and suspended sediments (Fig.20). They were carried by moderate and consistent current energy but influenced and deposited by high bidirectional marine energy current (tidal waves).

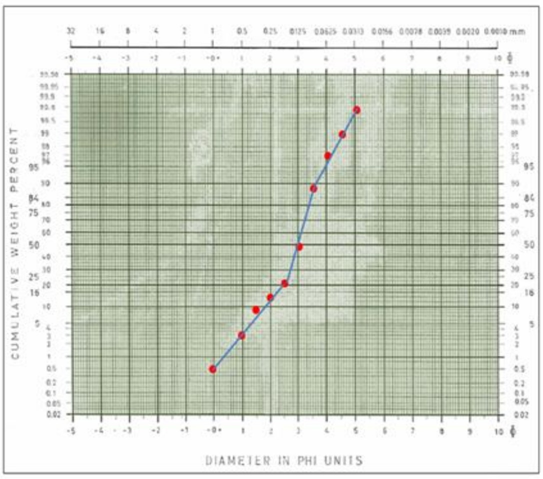


Figure 19: Log probability curve for Fugar Sandstone (Sample A2)

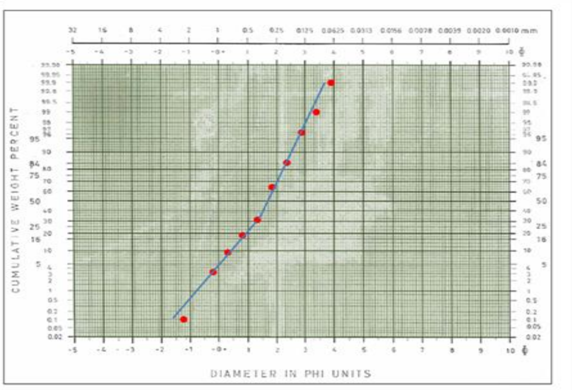


Figure 20: Log probability curve for Fugar Sandstone (Sample A4)

Paleoenvironment of Deposition

The values of multivariate parameters shown in Tables 9-11 and deductions from Figs. 21-22 suggest environment of deposition to fluctuate from continental to marine.

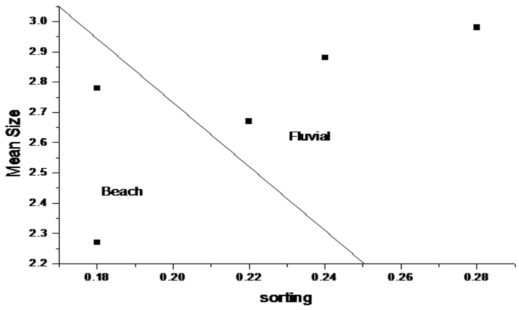


Figure 21: Bivariate Plot of mean size against Sorting for Fugar Sandstone (After Friedman, 1967).

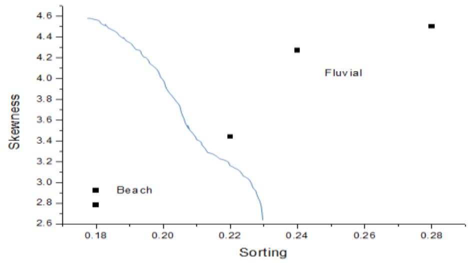


Figure 22: Bivariate Plot of skewness against Sorting for Fugar Sandstone (After Friedman, 1967).

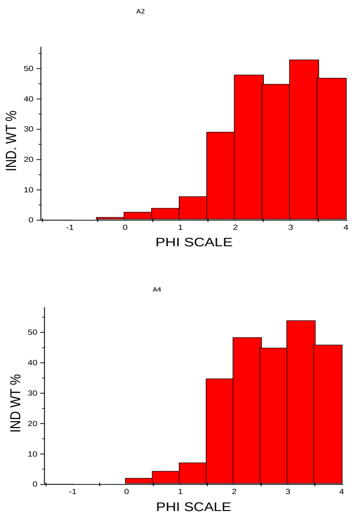


Figure 24: Histogram plots representing unimodal pattern for samples A2 and A4 samples

Paleocurrent Direction

Paleocurrent direction of the Fugar Sandstone located along Ifon – Uzebba road was determined by taking the dip values of cross-beddings. The values obtained are as follows: 140/70°E, 144/62°E,132/62°E,160/68°E,142/58°E,144/76°E,118/72°E,130 /64°E,140/56°E,142/78° E,140/54° E,146/58° E,134/66° E,148/70° E, 148/78° E,150/62° E,140/52° E,128/56° E,120/66° E,160/54° E,158/74° E,166/52°E. The values were calculated and the palecurrent direction through the azimuth was derived and drawn as presented in Figure 25.

Table 13: A Generalized values of Paleocurrent Direction of the Cross-bed Azimuths of Fugar Sandstone

CLASS INTERVAL	TALLY	FREQUENCY	FREQUENCY (%)
110 - 140	~~1111~~ 1111	10	53
141 - 170	~~1111~~ 1111	9	47
171 - 200			

Mean vector Azimuth = Tan^{-1} Σ{ (sin A)/(Cos A}
Where Σ Sin A= 11.9056
Σ COSA = -17.0175
Therefore, MVA = Tan^{-1}11.9056 /–17.0175
= Tan^{-1} (-0.6996) = -34
Hence MVA = -34 + 180
= 145°
Variance = Σ (A – MVA)^2 /(N – 1)
A = azimuth
MVA = Computed mean vector azimuth (145°)
N = total number of outcome (22)
Therefore, Variance = 3382/ (22 – 1)
= 3382/21
= 161

Evidence from Rose diagram plot shown in Figure 24 suggests that the direction of paleocurrent during the deposition of Fugar sandstone was in the southeastern direction, while provenance was from northwestern area of the basin. However, substantial amount of the particles might as well been sourced from the basement complex of western Nigeria.

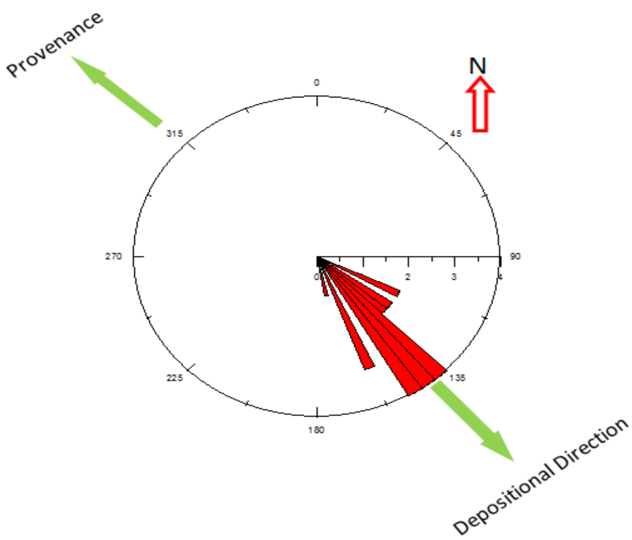


Figure 24: Rose Diagram showing Paleocurrent Pattern for Fugar Sandstone

Heavy mineral suites observed from the samples of Fugar Sandstone are zircon, tourmaline, rutile, garnet, epidote, staurolite, spinel, and titanite together with the opaques heavy minerals. These are evidence of low to medium grade metamorphic rock as the main source of the sediments. However, the possibility of other sources for the supply of sediments cannot be ruled out because of the presence of the sub-angular to sub-rounded titanite which suggests an acid igneous rock derivative. The ZTR index values for mineralogical maturity range from 35.9% to 50.0%, suggestive of mineralogically sub-mature sediments, while preponderance of Rutile as ultrastable minerals, suggest a metamorphic sourced rock.

Conclusions

Integrated interpretations from sedimentological methods have revealed that the sandstones are deposits of fluvial to deltaic environments, texturally submature to mature; mineralogically submature to mature, sublitharenite tending closely to quartzarenite of dominantly metamorphic humid and recycled orogenic provenance (Lokoja Bassange) and texturally matured Fugar Sandstones.

Thin section petrography and heavy mineral analysis of Lokoja Bassange and Fugar sandstones studied showed that they are near source sediment at the base and overlain by far distance transported sandstone facies derived from the recycled sedimrntary rock

Indices for paleoenvironmental reconstruction based on bivariant plots indicate fluviatile to near shore deposits.

Acknowledgement

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